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SUMMARY PAGE

THE PROBLEM

The increasing complexity of display and control instrumentation in modern high performance aircraft has the potential to overload the human operator and result in diminished system performance. Interactive voice technology has been proposed as a method to reduce the high workload placed on the pilots of military aircraft. This report presents the results of an experiment designed to evaluate the effects on human performance of vocal versus manual response modalities on single and multiple tasks simulating some conditions of flight.

FINDINGS

Results indicated a significant increase in performance precision on a psychomotor task when a vocal, rather than a manual response mode was used in the simultaneous performance of multiple tasks. These results suggest that human performance on visually oriented multiple tasks requiring simultaneous execution may be improved if some of the work effort can be performed using a vocal input/output.

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INTRODUCTION

The increasing complexity of display and control instrumentation in modern, high performance aircraft holds considerable potential for overloading the sensory/motor systems of the human operator and diminishing system performance. Interactive voice technology has been proposed to alleviate the information flow burden by redistributing certain information display and control functions from visual-manual to auditory-vocal, perceptual-motor mechanisms. Voice technology has the potential to improve human performance in a variety of tasks which are now performed with the eyes and hands. In high demand aviation environments, for example, voice technology would allow operators to interact vocally with an onboard computer, in order to select weapons, switch radar modes and radio frequencies, locate and paint enemy targets, release chaff and flares, and acquire information auditorily (e.g., threat location and warnings, airspeed, altitudes, g-force, closing rates, fuel state), while maintaining a visual orientation outside the cockpit.

The successful implementation of interactive voice devices in work environments depends on equipment reliability, user acceptance, and most importantly, the effective integration of man and machine. Interactive voice systems must not impose performance demands on the operator that would interfere with concurrent activities. Not only must interactive voice devices be effective in complex noise environments, they must also be insensitive to changes in the operator's voice characteristics which result from gravitational forces, vibration, workload and other inflight stressors. The present effort sought to compare the efficiency of vocal versus manual responses to one task while the operator simultaneously executed two continuous, compensatory tracking tasks.

METHOD

SUBJECTS

Sixty student naval aviator volunteers participated in the study. Fifty-six subjects, 16 Marine lieutenants and 40 Navy ensigns, were awaiting entry into the primary portion of the flight training program at Whiting Field, Florida. Three subjects were Navy ensigns preparing to enter the Naval Flight Officer training program. One additional subject had recently completed the Navy training program in the helicopter flight training pipeline.

APPARATUS AND PROCEDURE

Selected as tasks for the experiment were a complex psychomotor task (PMT) (requiring coordination of a subject's right hand, eyes and feet to position two visual cursors on a cathode ray tube) and a dichotic listening task (DLT) (requiring selective attention, left hand finger positioning, and vocal responses to an auditory presentation). Subjects first performed the PMT and DLT tasks separately and then in combination.

<u>Psychomotor Task (PMT)</u>. A psychomotor task (PMT) was used to represent the visual/psychomotor component of the simulated flight task. Subjects were required to maintain two electronically configured cursors on a fixed target of a CRT, using the floor-mounted control stick and foot pedals of a Systems Research Laboratory Psychomotor Test Device (1). The subject controlled an upper cursor with the control stick using the right hand, and a lower cursor by operating rudder pedals with the feet. Performance data were obtained during four consecutive, 5 minute test sessions, separated by rest periods of 90 second duration. The PMT performance measure was a machine-generated cumulative error score for each 5 minute session. The error score was derived automatically from .01 inch deviations from an ideal or "target" position on three (x, y, and z) axes of the visual display, and added together to provide a "total error" score. Tape recorded instructions were presented via headphones. A diagram of the experimental apparatus is at Figure 1.

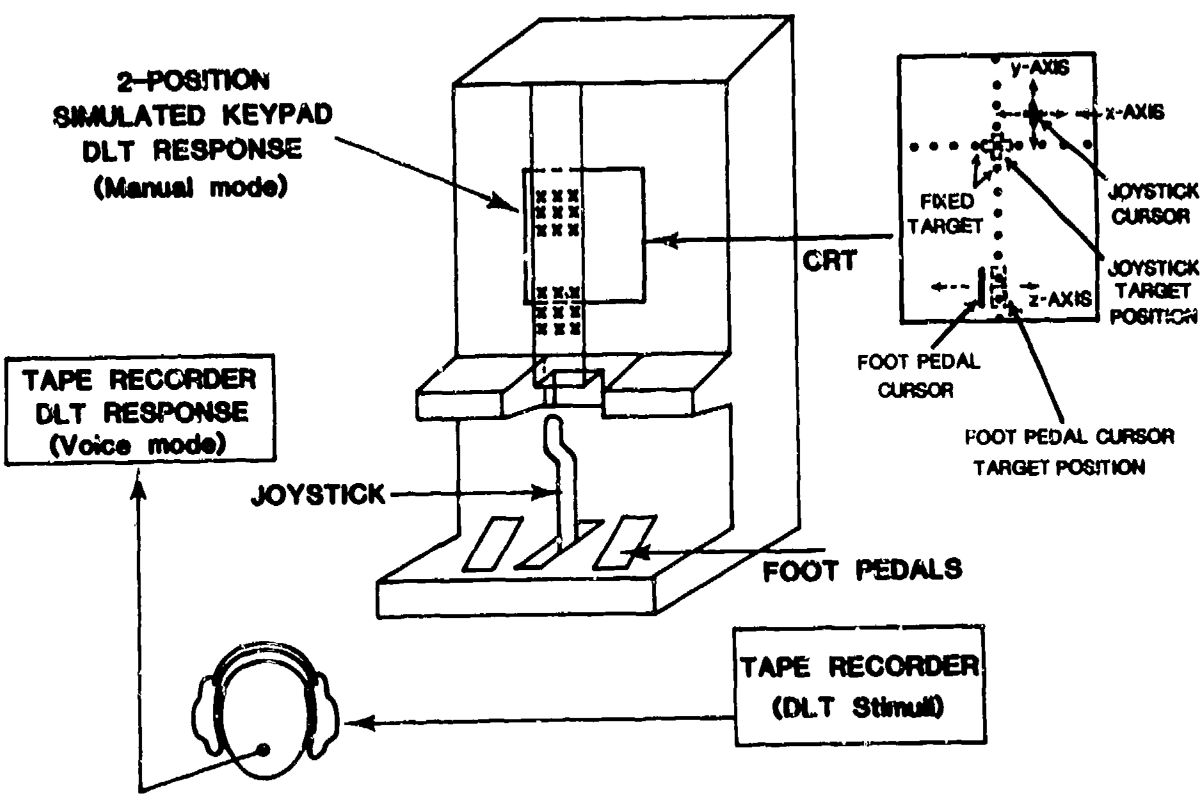

Figure 1. Experimental Apparatus.

Dichotic Listening Task (DLT). A dichotic listening task (DLT) patterned after that developed by Gopher (2) and Gopher and Kahneman (3) and subsequently modified at this laboratory (4) was used to represent the communications and attention management component of the simulated flight task. The DLT stimuli consisted of letter-digit strings which were presented dichotically to subjects during three sets of 24 listening trials. The subjects were instructed to maintain attention to one ear while ignoring the other ear and to report the digits presented to the designated ear in the sequence of their occurrence. An illustrative DLT trial is depicted in Figure 2.

PART I

Left Ear R 8 N S M Y 2 G B 7 F L 6 R L 5

"Right" (Vocal Channel "attend" Command)

Right Ear Y L 3 S R 4 F Z 9 X F Ø F N 1 L

PART II

Left Ear B F 4 3 7 9

"Left" (Vocal Channel "attend" Command)

Right Ear G L 1 5 6 2

Figure 2. DLT Trial Example

A different subject response modality was used for each set of listening trials (written, keypad, or vocal response). The three sets of listening trials were separated by 90 seconds during which time the test administrator read the instructions for the subsequent set of listening trials. A dual-channel tape recorder and binaural headphones were used to present the letter-digit strings at a listening level of 72 dB/Leq (re: 20 μ Pa). A clear plastic simulated keypad was mounted on the PMT device so that it was centered in the field of view horizontally and vertically (design eye level--position "one") and at a lower (30° below design eye), but horizontally centered location (position "two"). Half of the subjects used keypad position "one" while the remainder used keypad position "two" throughout all experimental conditions. For separate and combined task conditions, the subjects were instructed to make keypad responses with the left hand, while maintaining the right hand on the PMT control stick.

Keypad responses were visually monitored and recorded on magnetic tape by the test administrator. Vocal responses by the subjects were tape recorded for later analysis. Written responses were marked by the subjects on an answer sheet. The performance measure for the DLT was the average number of correct responses per 12 trials for each response method. DLT response methods and order of presentation of the PMT and DLT were counterbalanced across subjects and experimental conditions in both single-task and multi-task performance. A subject is shown performing in the Multi-task condition in Figure 3.

Figure 3. A subject performing in the multi-task condition

Multi-task Performance (PMT) and (DLT). Subjects performed the DLT and PMT simultaneously (a 12 trial DLT and PMT session of 5 minute duration). The onset of the DLT occurred 30 seconds after the onset of the PMT and terminated 1.5 sec before PMT cessation. The subjects used keypad and vocal responses alternately in performing the DLT.

RESULTS

SINGLE TASK PERFORMANCE

Performance means and standard deviations for the PMT and DLT single tasks are presented in Table I. As an inspection of Table I indicates, there was substantial improvement in PMT performance over repeated sessions. A repeated measures, analysis of variance (see summary table in Appendix A) indicated session 1 (highest error) to be significantly different, (F [3, 177] = 18.9, $p < .01$) from sessions 2, 3, and 4. Scores for the latter three sessions were not significantly different from each other. A repeated measures analysis of variance (see summary table in Appendix B) also revealed significant differences between DLT performance means (F [2, 118] = 12.9, $p < .01$) for the three response modalities. Written responses provided the most efficient means of responding to the DLT task followed in order by keypad and vocal response modalities. Written and keypad response modalities yielded similar performance means, and both methods resulted in significantly higher performance than vocal responses. Practically, however, the differences were small. A paired sample t-test (t [58] = .24) indicated that keypad location on the PMT device did not significantly affect single task DLT performance.

Table I

Single Task Performance
Psychomotor and Dichotic Listening

Psychomotor (PMT) Total Error			Dichotic Listening Task (DLT) *Number Correct Responses*		
Session	Mean	S.D.	Response Method	Mean	S. D.
1	18,254.1	14070.2	Written	106.0	2.2
2	11,804.2	8078.2	Keypad	105.2	2.7
3	10,458.4	6151.7	Vocal	103.9	4.6
4	10,318.1	6759.0			

*Average number correct for two series of 12 trials (average number correct possible = 108).

MULTI-TASK PERFORMANCE

Following single task performance each subject performed the DLT and PMT simultaneously. Mean performance scores and standard deviations obtained on the PMT and DLT in the multi-task condition are depicted in Table II. Repeated measures analysis of variance (F [2, 118] = 45.1, $p < .01$, see Appendix C) indicated a significantly lower error score on the PMT when the vocal response modality was employed for the DLT. Finally a repeated measures analysis of variance (see Appendix D) indicated that single t sk DLT keypad performance was significantly improved over both vocal and keypad response performance in the multitask condition (F [3, 177] = 11.44, $p < .01$). Keypad and vocal response methods in the multi-task condition and single task and multitask DLT vocal response performance was not significantly different.

As expected, error scores for later sessions of the single-task PMT were lower than error scores for the multi-task PMT. Similarly, single-task DLT scores obtained with the keypad response method were improved over keypad DLT scores obtained in the multi-task condition. Unexpectedly, DLT vocal response performance was not significantly different in the single-task and multi-task conditions. Finally, paired sample t-tests indicated that keypad location had no significant effect on either DLT performance (t [58] = 1.00) or PMT performance (t [58] = .52) in the multi-task condition.

Table II

Multi-Task Performance
Psychomotor and Dichotic Listening

Dichotic Listening (DLT) Number Correct Responses			Psychomotor (PMT) Error Scores Combined	
Response Method	Mean	S.D.	Mean	S.D.
Keypad	101.6	7.2	25109.5	19533.6
Vocal	102.4	5.4	15841.2	15205.3

DISCUSSION AND CONCLUSIONS

The data support an expectation of improved multi-task performance if selected tasks can be performed through vocal interaction. In this experiment subject performance deteriorated during multi-task performance (compared with single-task performance) regardless of DLT response modality. However, deterioration on the PMT was not as severe when a vocal, rather than a keypad, response modality was used in performing the DLT. Response modality did not affect DLT proficiency in the multi-task condition, but performance using keypad responses in the multi-task condition was poorer than keypad response performance performed in the single-task mode. The ability of the subjects to exhibit DLT performance in the Multi-task condition (vocal response modality) comparable to single-task DLT performance was an unexpected result. Although the investigators had anticipated problems with masking of the target auditory signals by the subjects' own vocal responses, none of the subjects reported any serious masking difficulties and the investigators were surprised by the ease with which the subjects performed the DLT (and the PMT) in the multi-task, vocal response condition. These results indicating improved multi-task performance using voice response, support similar findings by other investigators (5, 6, 7) even though the experimental tasks employed were dissimilar.

These findings indicate a significant increase in performance precision on a psychomotor task as a function of the use of a vocal response method for a second simultaneously performed task. The results have important implications for the performance of multiple, complex aviation tasks which are highly visually loaded, and lend support to theory (8, 9) suggesting that performance on multiple visual tasks may be improved if some of the tasks requiring simultaneous or near simultaneous execution, can be performed using a vocal input/output and vice versa. Examples of aviation task scenarios which could possibly benefit from interactive voice technology include nap-of-the-earth flight, bombing maneuvers, anti-submarine warfare and air combat maneuvering.

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APPENDIX A

Psychomotor (PMT) Single-Task Performance Summary
(6Ø Subjects - Error Scores Combined)

Session	Mean	S.D.
1	18254.13	14Ø7Ø.18
2	118Ø4.18	8Ø78.18
3	1Ø458.42	6151.67
4	1Ø318.12	6758.99

ANOVA

Source	DF	SS	MS	F Test	Sig. Level
Total	239	2299952.96			
Between Subjects	59	1253176.68			
Treatments	3	254Ø9Ø.78	84696.93	18.912	.ØØ1**
Error	177	792685.49	4478.44		

Summary of Simple Contrasts

Session 1 significantly different from sessions 2, 3, 4.
Sessions 2, 3, and 4 were not significantly different.

APPENDIX B

Dichotic Listening (DLT) Single-Task Performance Summary
(60 Subjects - Average of Two 1/2 Trial Sessions)

Response Method	Mean	S.D.
Written	105.99	2.24
Keypad	105.25	2.69
Vocal	103.88	4.61

ANOVA

Source	DF	SS	MS	F Test	Sig. Level
Total	179	2098.94			
Between Subjects	59	1333.11			
Treatments	2	137.26	68.63	12.88	.001**
Error	118	628.57	5.33		

Summary of Simple Contrasts

Written and keypad response methods significantly different from vocal responses.

Written and Keypad response methods were not significantly different.

APPENDIX C

Psychomotor (PMT) Single-Task and Multi-Task Performance Comparison (60 Subjects)

PMT Single-Task Performance	Mean	S.D.
Session 4	10318.12	6758.99

PMT Multi-Task Performance	Mean	S.D.
With Keypad DLT	25109.47	19533.56
With Vocal DLT	15841.22	15205.26

ANOVA

Source	DF	SS	MS	F Test	Sig. Level
Total	179	4555177.24			
Between Subjects	59	3008002.39			
Treatments	2	670278.26	335189.13	45.110	.001**
Error	118	876796.59	7430.48		

Summary of Simple Contrasts

All performance measures are significantly different.

APPENDIX D

Dichotic Listening (DLT) Single-Task and Multi-Task Performance Summary (60 Subjects)

DLT Response Method	Mean	S.D.
Keypad, Single-Task	105.25	2.69
Vocal, Single-Task	103.88	4.61
Keypad, Multi-Task	101.63	7.21
Vocal, Multi-Task	102.38	5.37

ANOVA

Source	DF	SS	MS	F Test	Sig. Level
Total	239	6903.08			
Between Subjects	59	4046.83			
Treatments	3	462.81	154.61	11.44	.001**
Error	177	2392.43	13.52		

Summary of Simple Contrasts

Single-Task keypad response performance significantly different from multi-task performance using keypad or vocal response methods.

Single-task vocal response performance is significantly differen from multi-task keypad response performance.

Single-task vocal response and multi-task vocal response performance is not different.

Multi-task keypad and vocal response performance is not significantly different.

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The increasing complexity of display and control instrumentation in modern high performance aircraft has the potential to overload the human operator and result in diminished system performance. Interactive voice technology has been proposed as a method to reduce the high workload placed on the

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pilots of military aircraft. This report presents the results of an experiment designed to evaluate the effects on human performance of vocal versus manual response modalities on single and multiple tasks simulating some conditions of flight.

Results indicated a significant increase in performance precision on a psychomotor task when a vocal, rather than a manual response mode was used in the simultaneous performance of multiple tasks. These results suggest that human performance on visually oriented multiple tasks requiring simultaneous execution may be improved if some of the work effort can be performed using a vocal input/output.